How I Perform the Maze Procedure

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Atrial fibrillation (AF) is one of the most common forms of cardiac arrhythmia. Some AF patients suffer from systemic embolism, hemodynamic compromise, acute physical discomfort (palpitation, near syncope, and more), and other side effects of antiarrhythmic drugs and anticoagulants. In 1991, Cox et al[1-4] developed the Maze procedure in which the atrium is incised and sutured in a Maze-like pattern in order to prevent macro reentries. Cox initially applied this Maze procedure to cases with isolated AF. However, it was believed that the chronic AF associated with mitral valve (MV) disease could not be cured by the Maze procedure. We tried to treat such chronic AF by the Maze procedure in 1992. The results confirmed that the Maze procedure was also an effective treatment for chronic AF associated with MV disease.[5,6] We have applied the Maze procedures to 11 cases of isolated AF, 305 cases of AF associated with MV disease, and 51 cases of AF associated with other types of heart disease between 1992 and 1999.

In the past, the multiple reentry theory and the multiple automatic foci theory were proposed in order to explain the mechanism behind AF. Moe[7] presented the multiple wavelets hypothesis, whereas Allessie et al[8] calculated the size of the leading circle based on the conduction velocity of the atrium and refractory periods, and also calculated the number of possible wavelets based on the size of the atrium. They theorized that AF becomes less likely to revert spontaneously to sinus rhythm in patients with more than six wavelets. Even in adults with five wavelets, AF is relatively harmless; however, if the atrium is enlarged by external factors such as MV disease, the possibility of contracting AF, along with its severity, increases dramatically. In contrast, the left atrial dimensions of isolated AF patients are not large, according to echocardiography results. In such patients, the conduction velocity of the atrium or refractory periods may be morbid.

The current results indicate that the Maze procedure is incapable of curing 20% of the cases involving chronic AF associated with MV disease. Approximately 50% of such associated cases remain as AF, and the rest remain as atrial tachycardia with isoelectric lines, which indicates micro reentry or automatic foci. It is simply impossible for these arrhythmias to be treated by the Maze procedure. The electrophysiological examination of three patients after surgery confirmed that the atrial arrhythmia was induced and terminated by pacing, its origin was extremely small, and the atrial activation spread radially. These patients suffered from atrial tachycardia caused by a micro reentrant circuit.

We feel that if the atrium is incised in a manner resembling hashing, total prevention of AF can be achieved. This process, however, leads to widespread pressure on the atrial myocardium, and a loss of the contracting function. Therefore, the Maze procedure is an ideal technique for effectively controlling the AF while minimizing incisions. Generally, because the macro reentry of an adult is 4 cm in diameter, a 4-cm incision in the atrium should be sufficient. Cox et al[1-4] developed this procedure—a general outline follows: (1) surgical incisions are performed in such a way that it is impossible for an activation impulse to travel from any point in the atrium and return to the same point without crossing an incision or a cryoablated line, which interrupts the electrical conduction; (2) of critical importance is the fact that the Maze procedure provides a route by which an impulse generated by the sinoatrial node can access the atrioventricular node to drive the ventricle; (3) several blind alleys along this main conduction route are also created to synchronously activate the atria, thus preserving the atrial transport function; and (4) a single pathway is preserved for conduction between the sinus node and the atrioventricular node.

Indication for the Maze Procedure

Isolated AF is not a fatal arrhythmia, and in almost every case, because symptoms and complications arising from AF can be controlled (although not cured) by pharmacological therapy, surgical indications should be considered very carefully. Present indispensable conditions that affect the surgical indications are: (1) AF is a drug refractory; (2) the AF symptoms are very severe or AF has caused systemic embolism; and (3) the patient requests a radical operation without pharmacological therapy.

Although simultaneous treatment for AF may be indicated, generally this is reserved for patients suffering from other heart disease who may require surgery. However, when the voltage of the F wave is nearly 0 mV, the diameter of the left atrium exceeds 70 mm, and the cardiothoracic ratio (CTR) exceeds 80%, the curative rate of AF falls below 50%. In addition, if a patient's cardiac functioning is not promising and the operative risk is high, or if the patient has undergone a previous operation and dissection of adhesion is difficult, the procedure is not recommended despite the indication.

Our Modifications of the Cox-Maze Procedure

Preserving the Function of the Sinus Node

We are attempting to improve the method further in order to use freezing as a substitute for incisions.[5,6] During the Cox-Maze procedure, the atrium is cut in a manner similar to a Maze in order to block the circuit; these incisions, however, also involve cutting the feeding artery of the sinus node. Cutting the sinus node artery may alter sinus node function after the operation. According to McAlpine,[9] the main sinus node arteries are the right, left, and posterior. There are also some unusual variations. Each person has one of these types of sinus node arteries. McAlpine explained that approximately 70% of sinus node artery approaches are behind the superior vena cava (SVC) to the sinus node. The Maze procedure is being improved in an attempt to preserve these arteries. Modifications suggested by Cox[1-4] also do not involve cutting the sinus node artery. Rather, Cox uses an incision in the atrium at the back of the sinus node because he feels that the sinus node artery originates from both the front and the rear. Because we feel that Cox's modified procedure still involves cutting the major sinus node arteries that approach behind the SVC, our modification cuts the anterior side of the sinus node. Our improvements involve freezing the sinus node artery, but 50% stenosis of the coronary arteries are induced by freezing, which is better than cutting. In our experience, the occurrence rate of sick sinus syndrome soon after the Maze procedure has been 80% (12 of 15 cases) for Maze II; 67% (26 of 39 cases) for Maze III; and 30% (45 of 150 cases) for our modification. Therefore, it can be concluded that the occurrence of sick sinus syndrome soon after operation was reduced significantly ($P < .005$) by our method. As the collateral artery expanded, however, the recovering rate of sinus rhythm rose to 93%, 95%, and 97% in Maze II, Maze III, and in our modified version, respectively.

In addition, our method maintains the direct connection between the sinus node and the Bachmann bundle. Coincidentally, our method is very similar to the radial operation, except for the incision encircling all four orifices of pulmonary veins.

The Size of the Atrium

Whereas Cox et al[1-4] have applied the Maze procedure primarily to patients with isolated AF, we have performed the Maze procedure mainly for patients suffering from AF associated with MV disease. The size of an atrium with isolated AF is close to normal, but that of an atrium with MV disease is extremely dilated, which could be one of the causes of AF. Allessie et al[8] stated that because the conduction velocity in humans is 80 cm/sec, and the refractory period is 150 msec, the wavelength of reentry in humans is 12 cm and the diameter of the reentry circuit is approximately 4 cm. Therefore, to make the Maze procedure more effective, atria that had dilated excessively were trimmed to approximately 4 cm. This method, however, is just a hypothesis. For the same reason, Sueda et al[10] hypothesized that only AF in the left atrium can be cured by the Maze procedure. In addition, both Batista's hypothesis and Lin's hypothesis may also be correct.[5,11]

Transection of the SVC

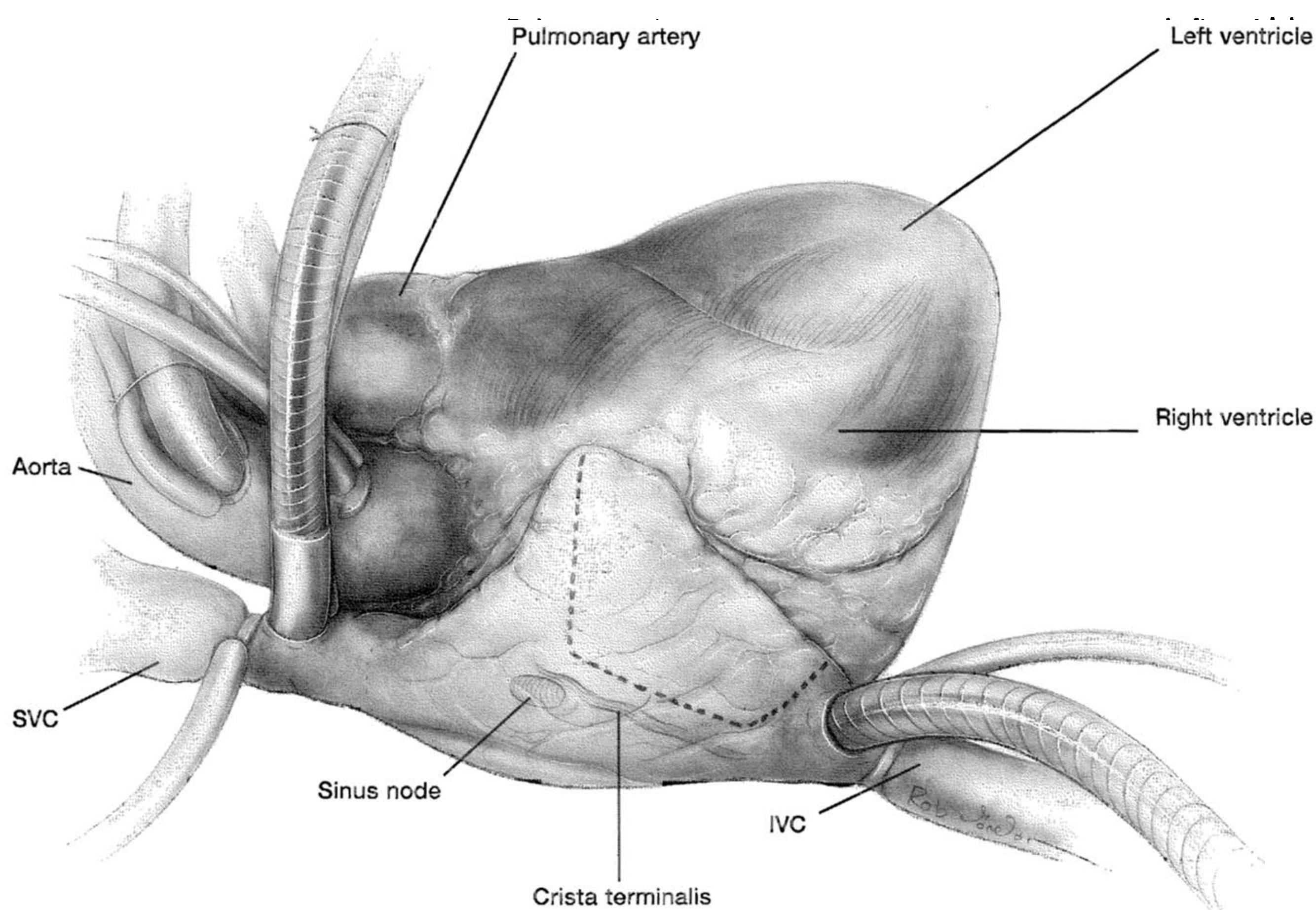
Temporarily transecting the SVC is effective for reducing operation time because it vastly improves observation of the MV. A denervated heart (a state induced by transecting the SVC) suppresses the occurrence of atrial arrhythmia. Tamai et al[12] reported that although a denervated heart also suppresses the increase of heart rate during exercise at 1 month postoperatively, recovery was observed within 6 months postoperatively.

Preservation of Both Atrial Appendages

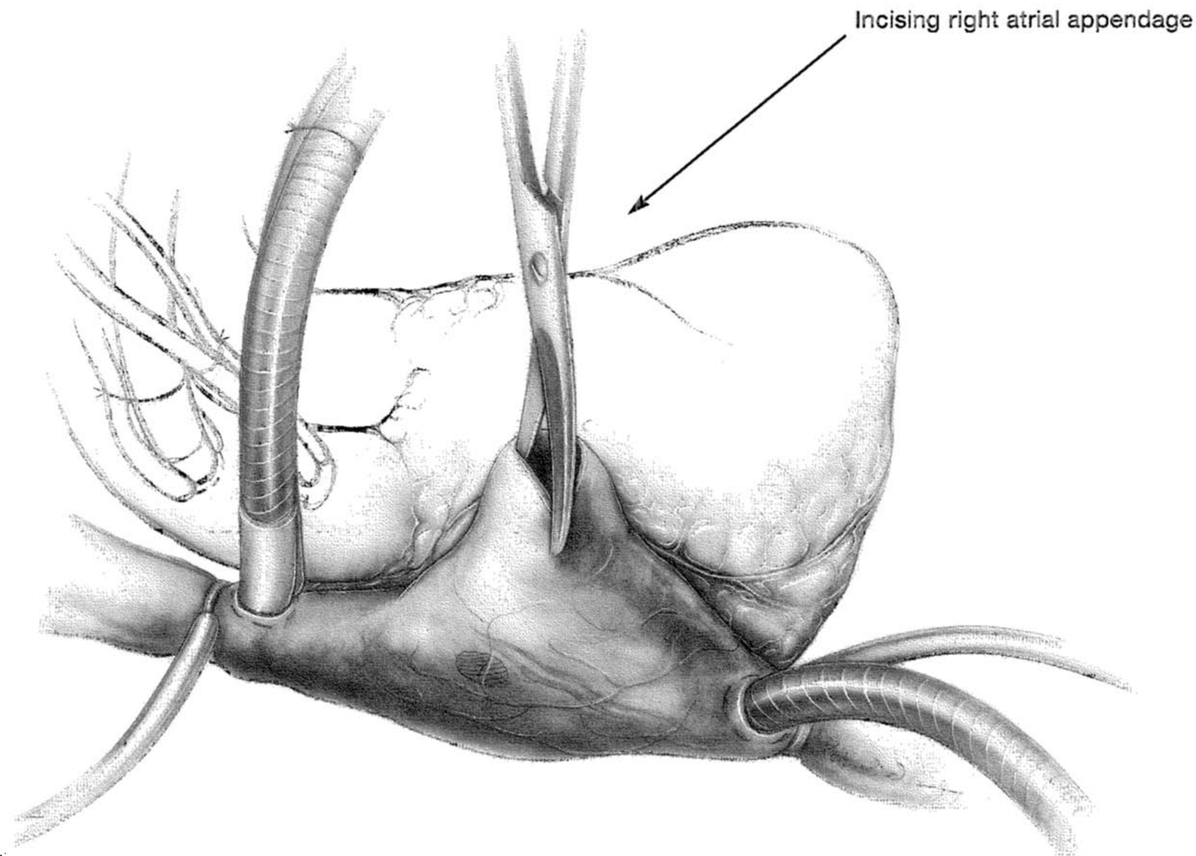
The amputation of the atrial appendages intercepts the reentry circuit around the appendages and prevents the formation of a thromboembolism. However, the amputation of the appendages also reduces the secretion of atrial natriuretic peptide.[13] Therefore, the preservation of atrial appendages maintains the urination function after operation. We preserve all of the right atrial appendage and part of the left atrial appendage.

SURGICAL TECHNIQUE

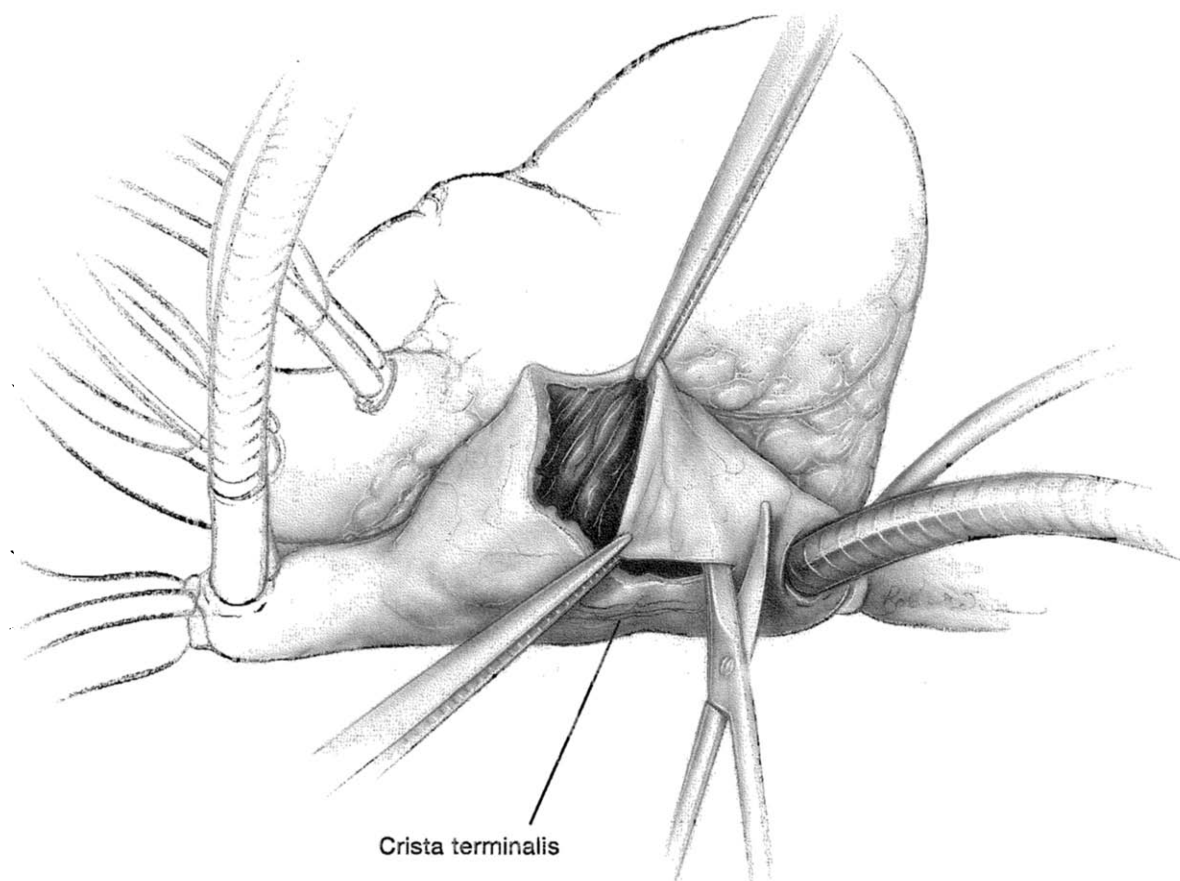
A median sternotomy is performed and the pericardium is opened longitudinally. The pericardium is incised upward to the SVC and the SVC is mobilized. After systemic heparinization, the aorta is cannulated through a purse-string suture in the ascending aorta. A right-angled venous return cannula is inserted through a purse-string suture in the SVC, just above the pericardium-SVC junction. A separate right-angled venous return cannula is then inserted through a purse-string suture in the lowest portion of the right atrium, near its junction with the inferior vena cava (IVC). An antegrade cardioplegia cannula is inserted into the ascending aorta. Umbilical tapes are passed around the SVC and the IVC. In addition, the SVC tape should be inserted below the azygos vein. Cardiopulmonary bypass is initiated. The following figures illustrate our technique.



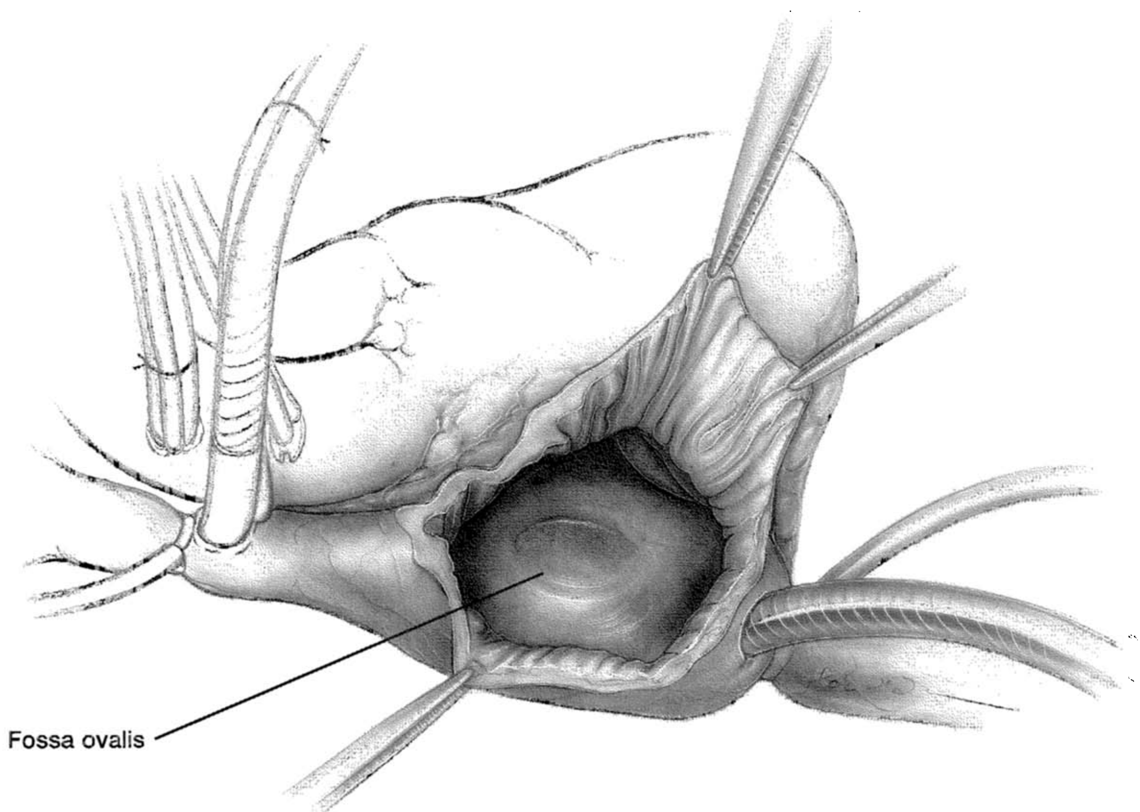
1 Incision line of the right atrium. Cardiopulmonary bypass is instituted and the umbilical tapes are secured around the SVC and the IVC. We prefer to perform the right-side incisions during beating heart in order to reduce the arrest time. (If an atrial septal defect exists, the right-side incisions are placed after the aortic cross-clamp.) Dashed lines show our incision lines. After all incisions of the Maze procedure are performed and the aorta is cross-clamped, cryoablation should be placed, because cryothermia infiltrate well to the myocardium without coronary perfusion.



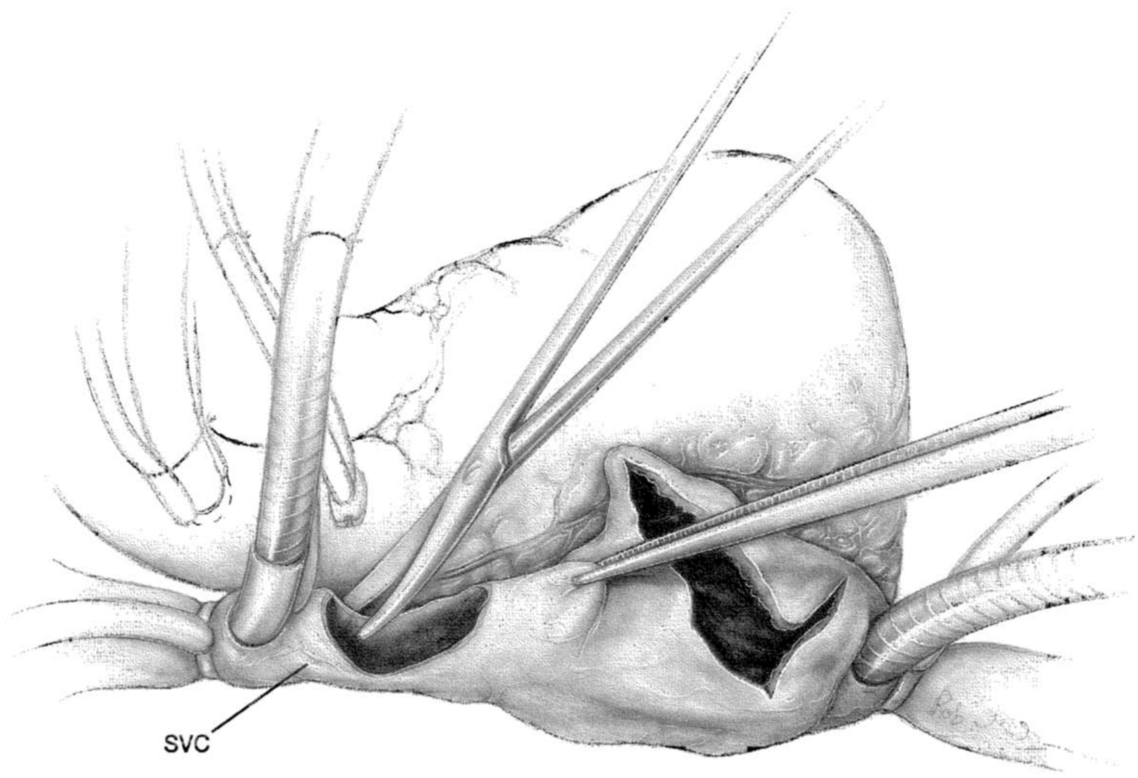
2 Incision of the right atrium (no. 1). The right atrial appendage is not amputated in order to maintain the secretion of atrial natriuretic peptide. The incision is placed from the top of the right atrial appendage toward the sinus node. All of the major trabecule on the right atrial appendage should be cut off in order to block the reentry here. Make sure that the surgeon or assistants do not hold a sinus node with tweezers. Later, cryoablation should be placed on the right-side atrial septum between the right atrial appendage and the fossa ovalis.



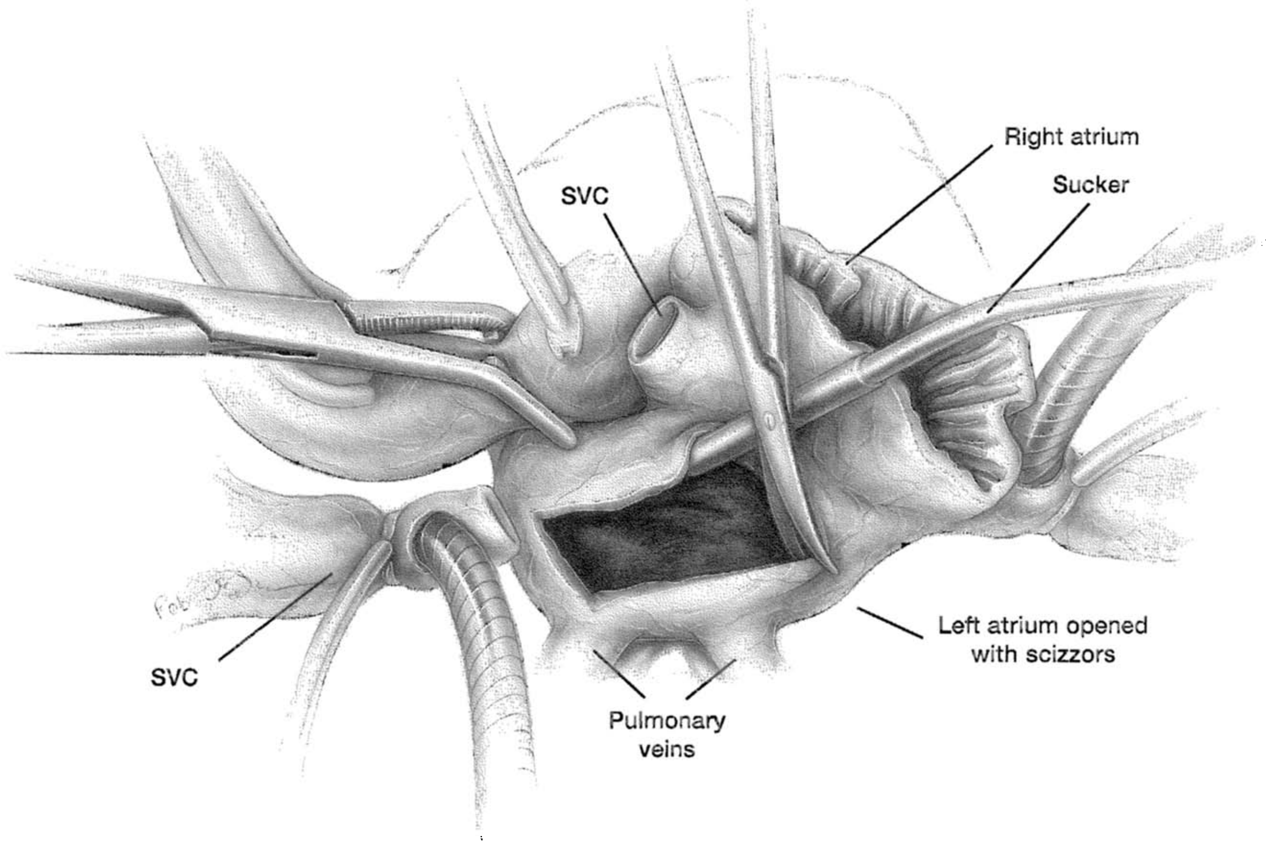
3 Incision of the right atrium (no. 2). When the incision approaches approximately 5 mm of the sinus node anteriorly, it is turned toward the IVC and placed approximately 5 mm anteriorly and parallel to the crista terminalis. When the incision approaches approximately 1 cm above the inferior venous cannula, it is turned toward the tricuspid annulus.



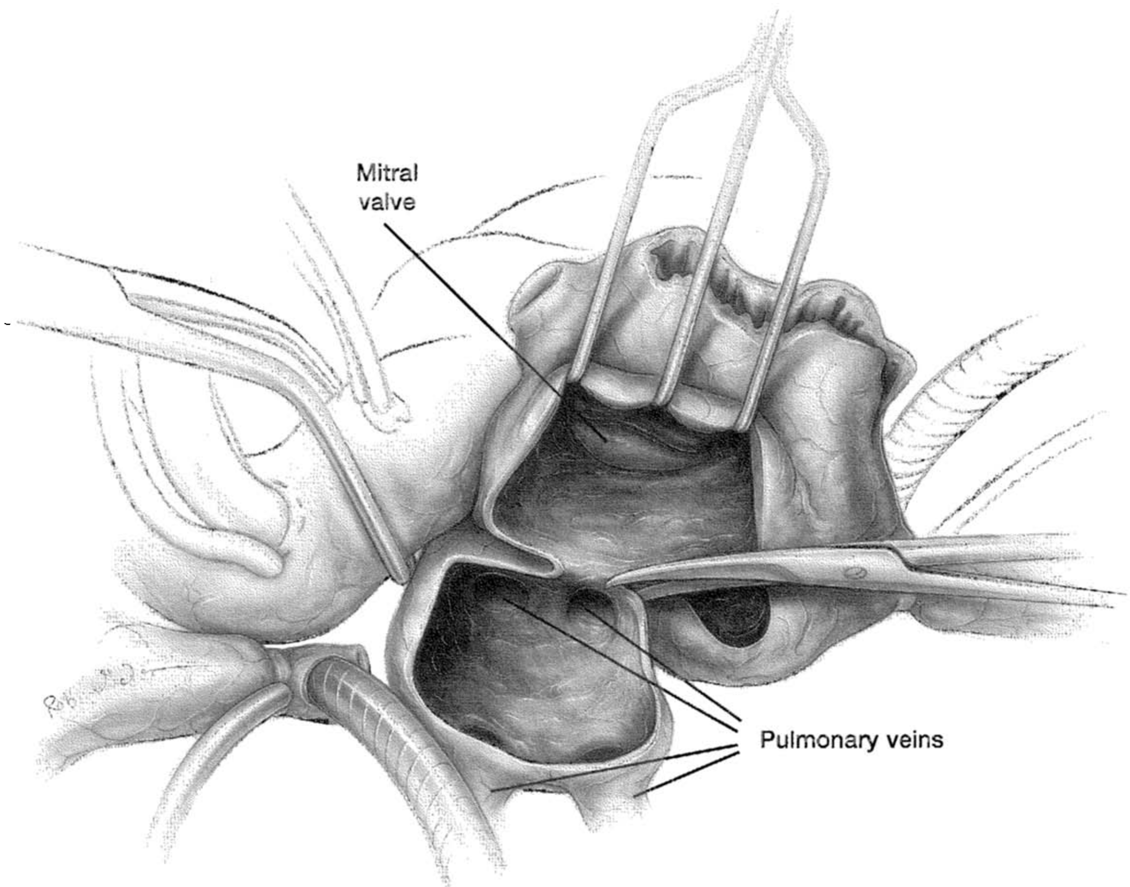
4 **Incision of the right atrium (no. 3).** When the incision approaches approximately 1 cm above the venous cannula, it is turned obliquely and downward to the tricuspid annulus, because the area of the bottom of right atrium is wide. The incision is stopped at the brink of the fat pad of the atrioventricular groove. The free wall of the right atrium can be opened like a door. Later the residual atrium between here and the tricuspid annulus should be cryoablated.



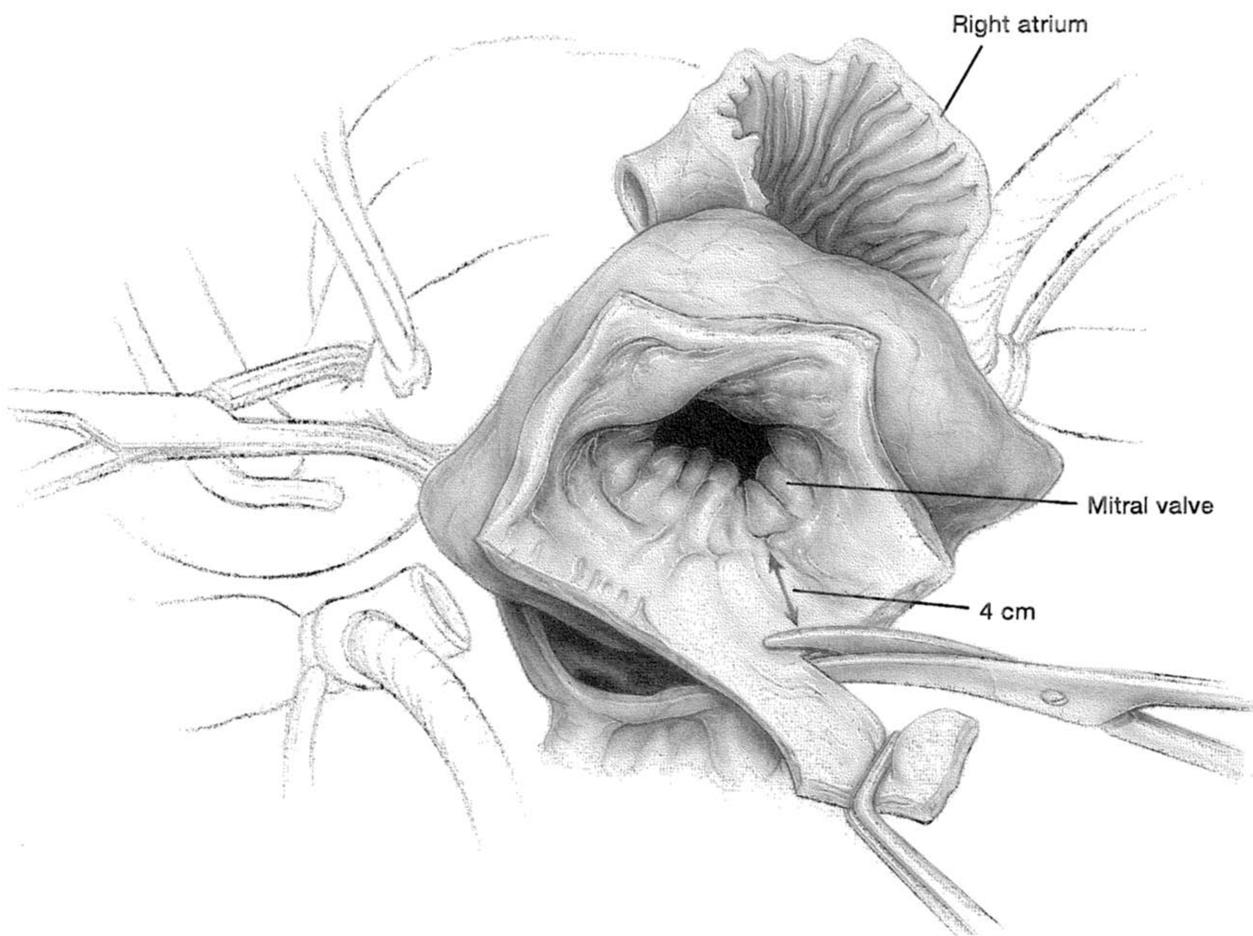
5 Transection of the SVC. The SVC is transected approximately 1.5 cm distal to the junction with the right atrium. This method is effective for reducing operation time, because it vastly improves observation of the MV. However, this method results in a denervated heart. If treatment of the MV is not necessary, this transection may not be necessary.



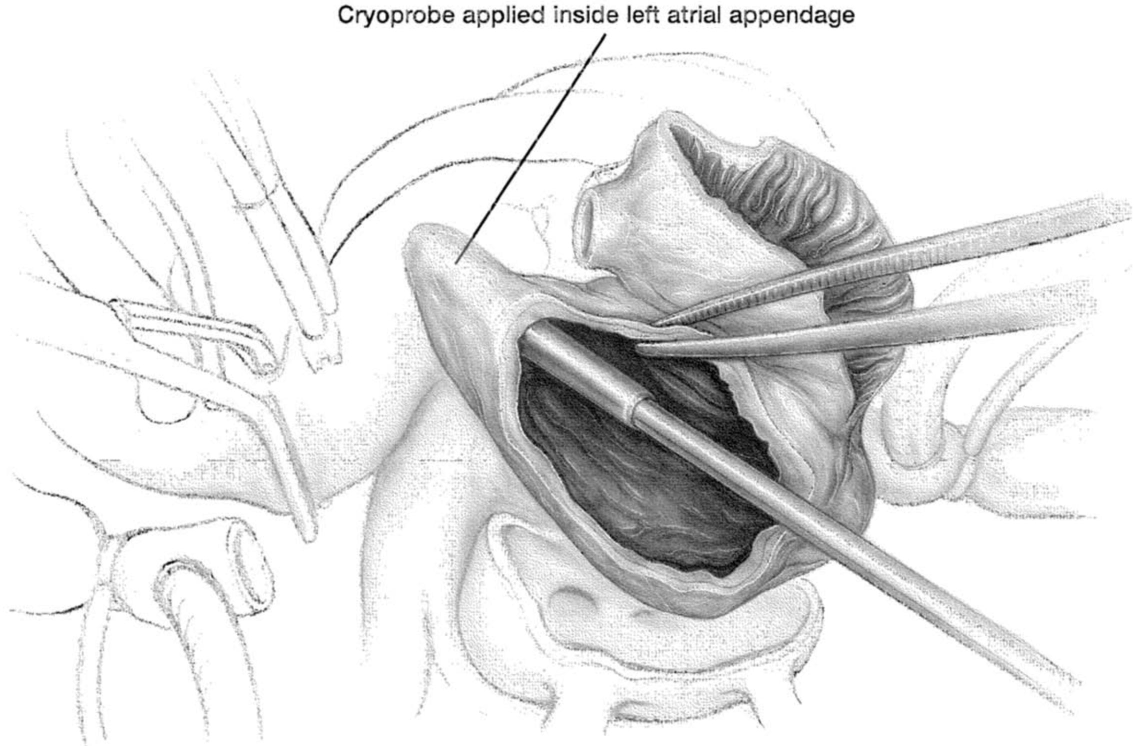
6 Incision of the left atrium (no. 1). The systemic temperature is reduced to 29°C. The aorta is cross-clamped and the heart is arrested with antegrade and retrograde tepid, cold-blood cardioplegic solution. After the institution of cardiac arrest, the left atrium is incised at the right side of the right pulmonary veins as in a regular mitral operation. During placement of the left-sided incisions, the vent tube is inserted into the left inferior pulmonary vein orifice, a maneuver that improves the operative exposure substantially. When the cardioplegic solution is infused, the bleeding point of the atrial coronary arteries should be found and sutured by a single knot because the continuous over-and-over suture cannot prevent arterial bleeding.



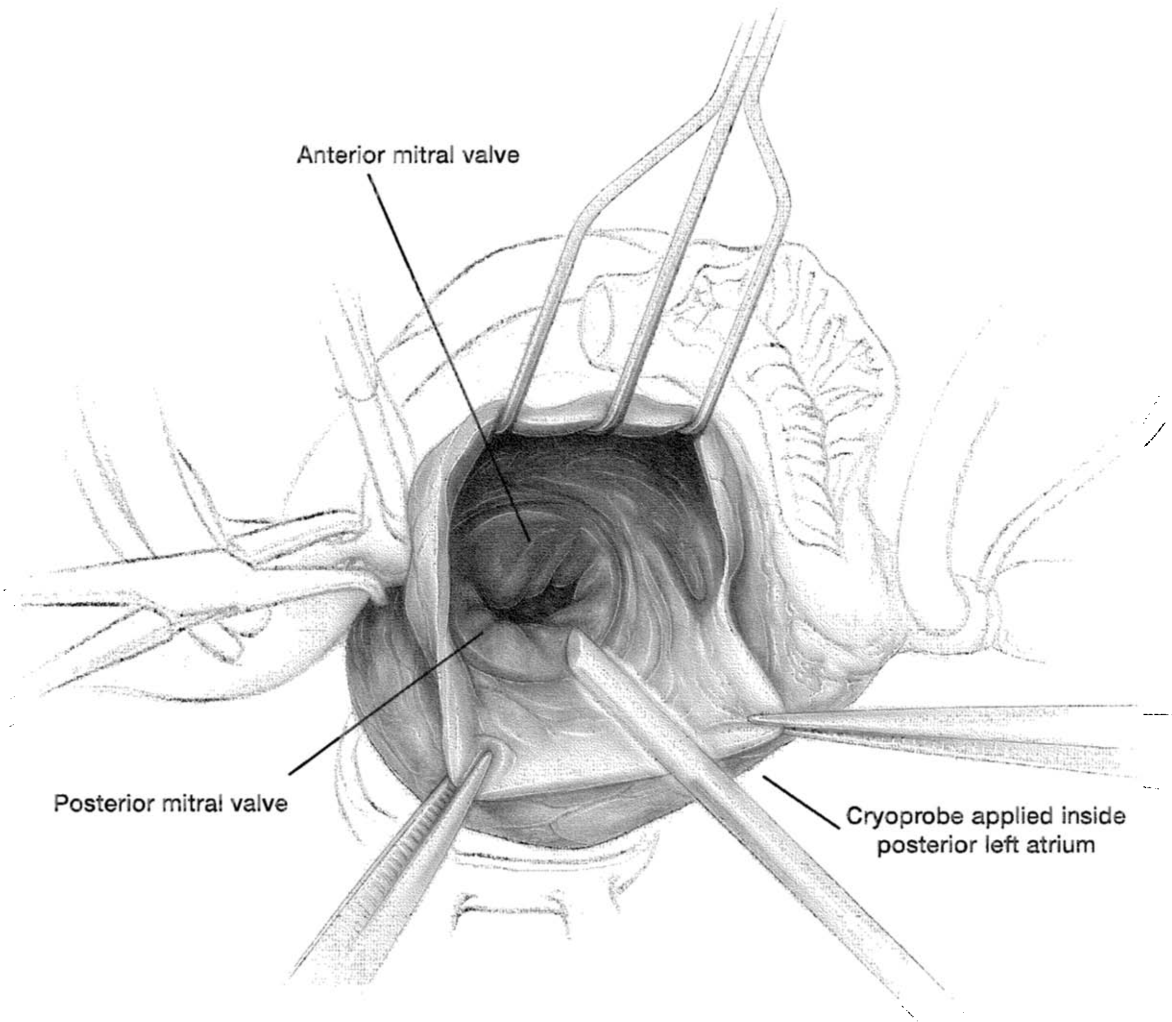
7 Incision of the left atrium (no. 2). The left atriotomy is then extended to encircle all four orifices of pulmonary veins. At the circumferential atriotomy, the left ventricle is completely disconnected from the four pulmonary veins. This disconnection and the transection of the SVC vastly improves observation of the MV. This method reduces the time required for the MV treatment. Exposure of the MV is helpful in educating less experienced persons on how to treat the MV. When this disconnection is sutured later, it will be difficult to determine the adequate points of the attachment. Therefore, it is very important to put several marks on the incision line during the circumferential atriotomy.



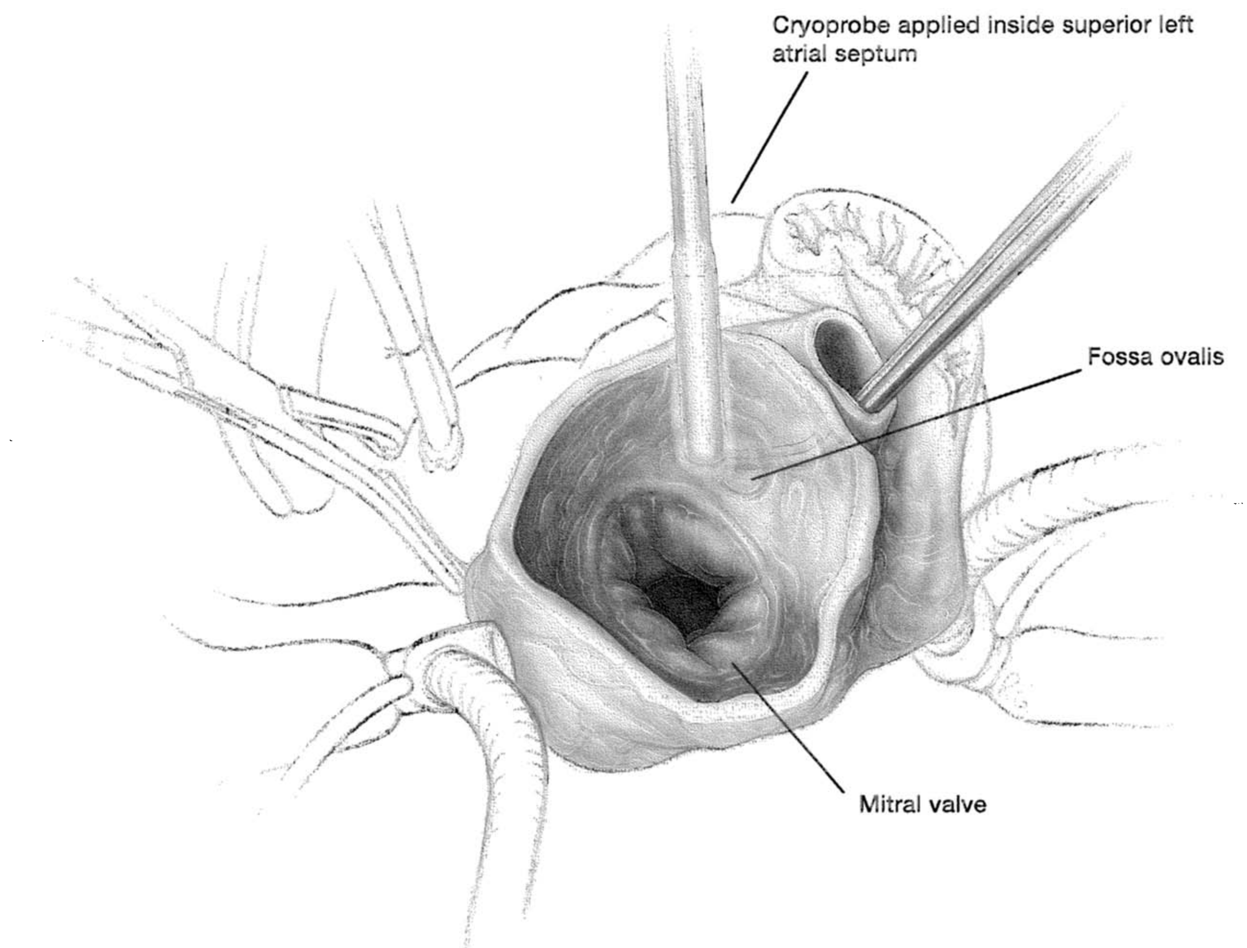
8 Cutting off the redundant dilated left atrium. The redundant atrial tissue is removed in order to ensure that the length of all portions of the atrium is under 4 cm. If the atrial area is larger than 4 cm, we hypothesize that macro reentry may occur.



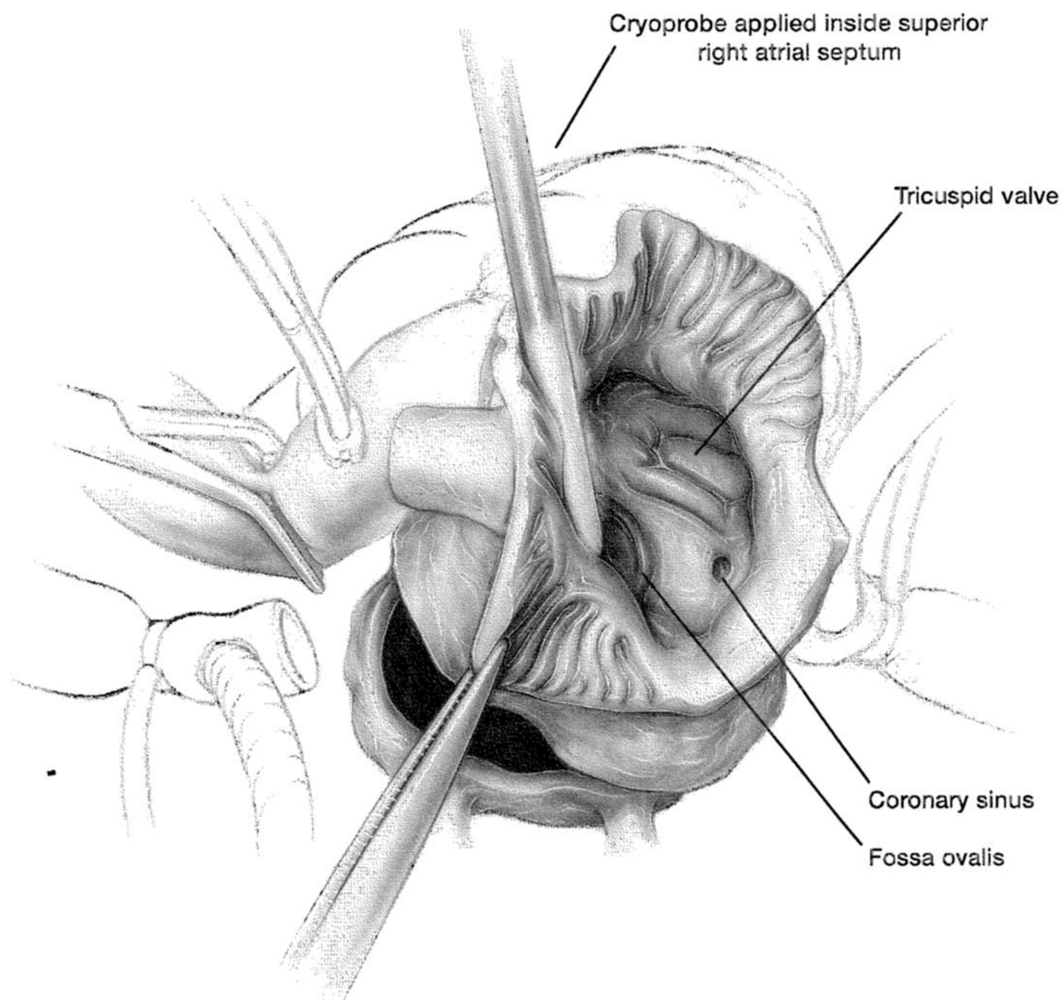
9 Cryoablation of the left atrium (no. 1). It is preferable that the probe of the cryomachine is narrow and long. We usually use a 142 system (Spembly, Inc, Andover Hampshire, UK). The temperature of cryoablation is usually set at −80°C, and cryoablation is halted when the entire atrial wall is frozen. This schema shows the cryoablation toward the appendage. This cryoablation interrupts the reentry around the left atrial appendage.



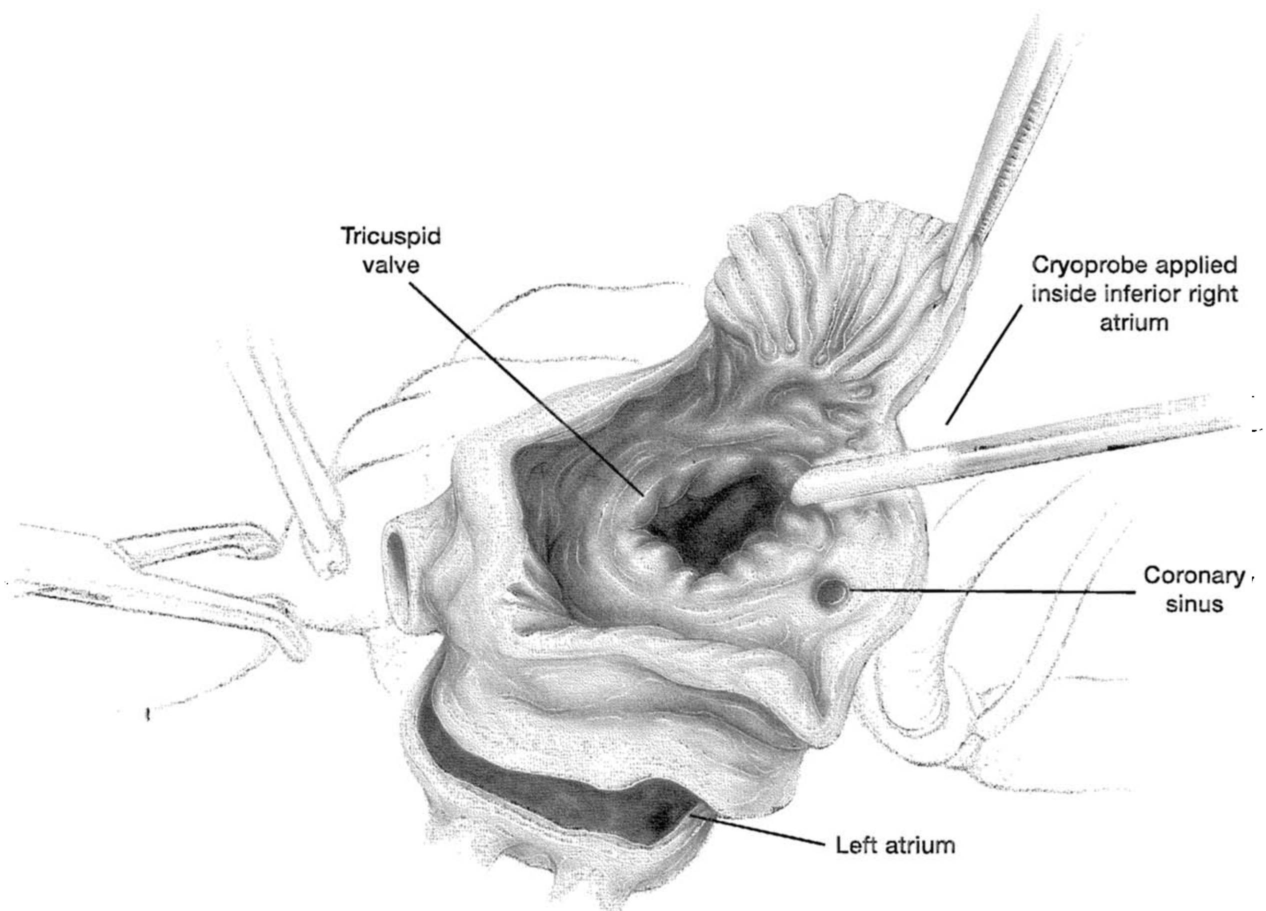
10 Cryoablation of the left atrium (no. 2). The cryoablation is performed on the posterior wall of the left atrium between the incision edge of the left atrium and the mitral annulus. Cryoablation should not be performed in the calculated time (eg, 2 minutes). Cryoablation should be halted when the transmural freezing is visible to the naked eye. The reason for this method is that the major coronary arteries should not be frozen. Pulling the fat pad of the atrioventricular groove is helpful in preventing the major coronary arteries from freezing. It is not risky to freeze the MV leaflet. This cryoablation interrupts the reentry around the MV annulus.



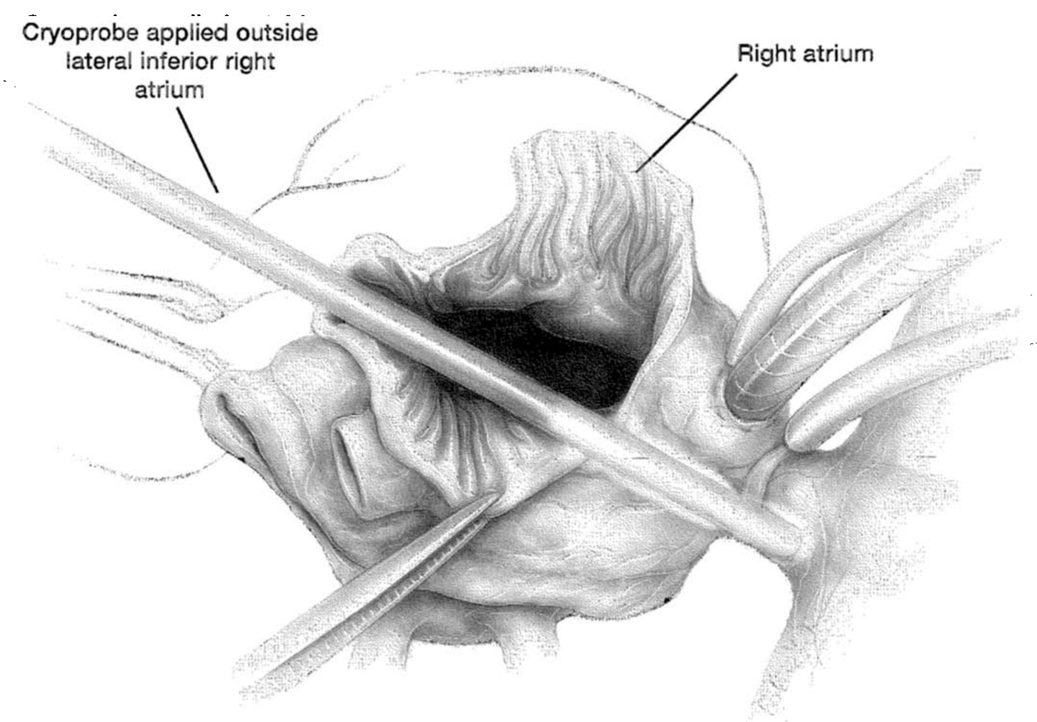
11 **Cryoablation of the left atrium (no. 3).** The cryoablation is performed on the left side of the interatrial septum between the incision edge of the left atrium and the back side of the fossa ovalis, which is pointed from the right atrium using tweezers. This cryoablated line is the backside of the cryoablated line of the right-side septum because the upper rim of the fossa ovalis is thick and it is difficult for the freezing to penetrate the interatrial septum. This cryoablation interrupts the reentry around the fossa ovalis.



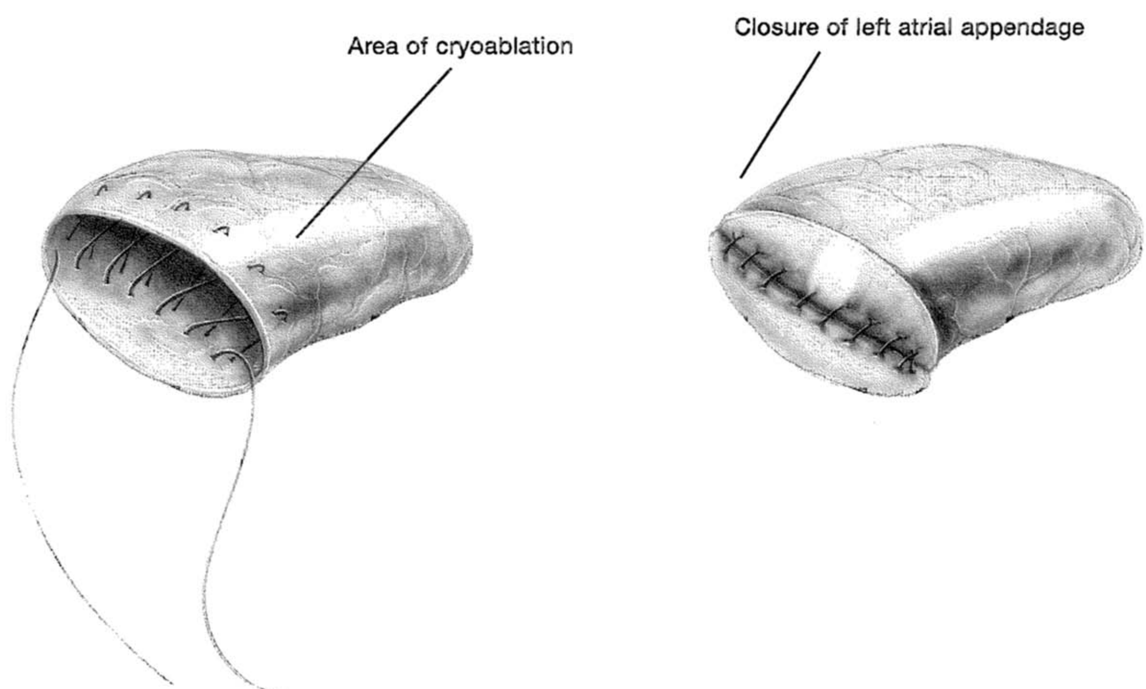
12 **Cryoablation of the right atrium (no. 1).** The cryoablation is performed on the right side of the interatrial septum between the right atrial appendage and the fossa ovalis. Cryoablation of the interatrial septum is performed from both the left and the right atria in order to reinforce the transmural penetration of cryothermia. This cryoablation also interrupts the reentry around the fossa ovalis.



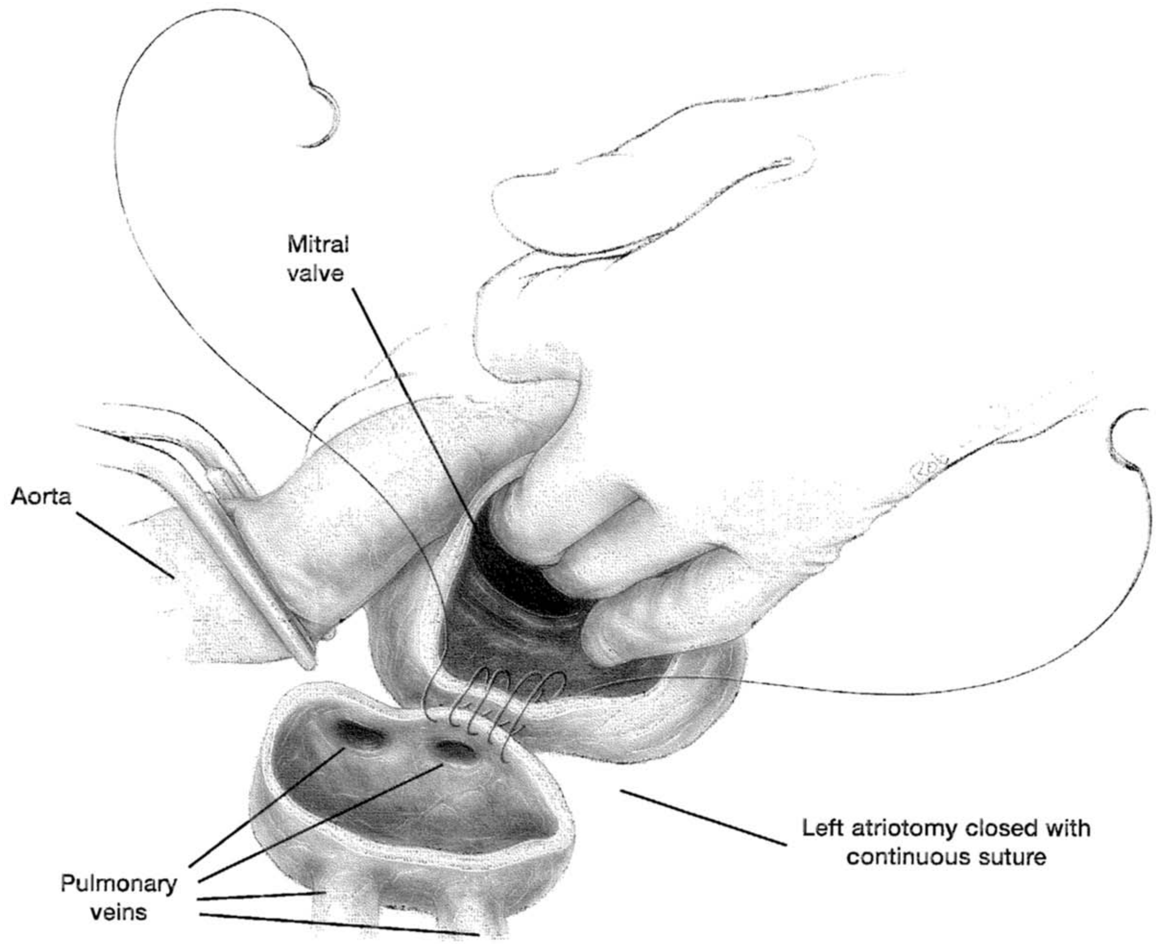
13 Cryoablation of the right atrium (no. 2). Cryoablation is then performed between the end of the right atriotomy and the tricuspid annulus. Pulling the fat pad of atrioventricular groove is helpful in preventing the major coronary arteries from freezing. It is not risky to freeze the MV leaflet. This cryoablation interrupts the reentry around the tricuspid valve annulus.



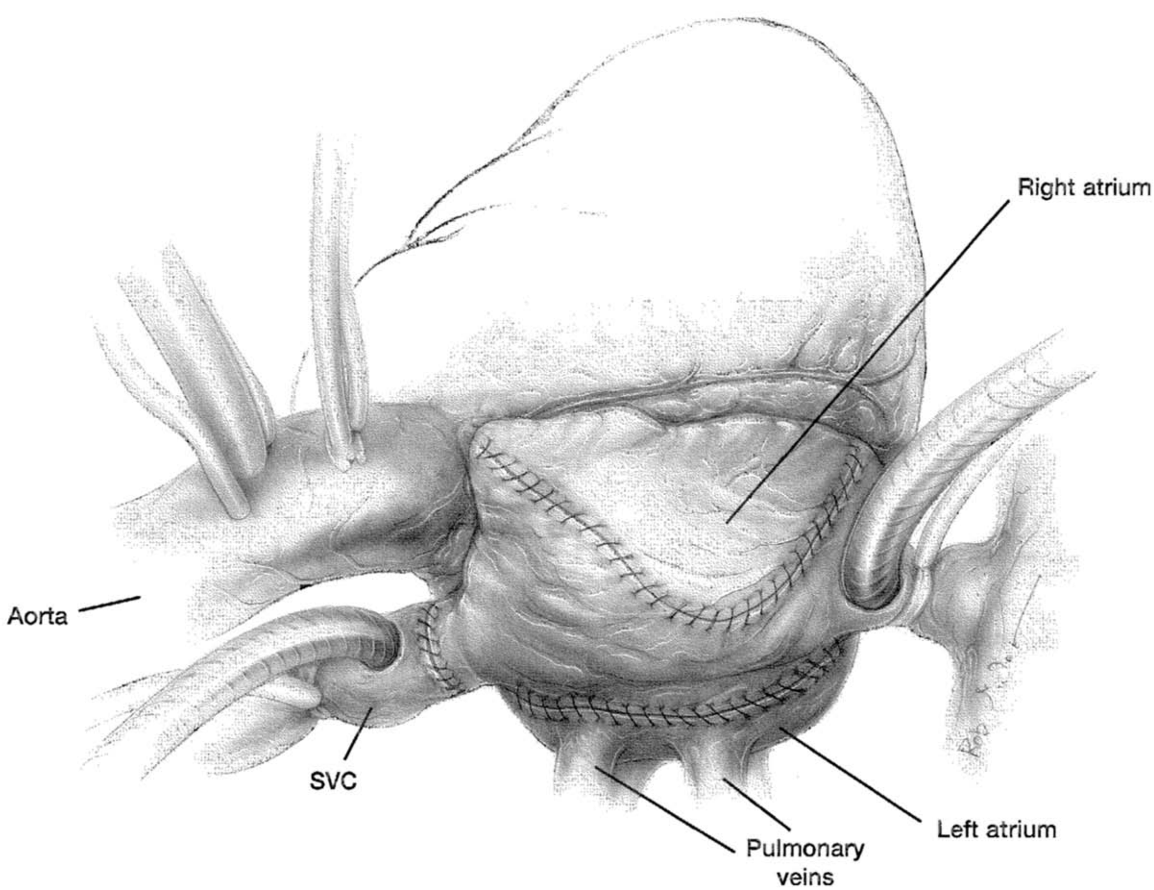
14 Cryoablation of the right atrium (no. 3). Cryoablation is then performed between the posteroinferior edge of the right atrial incision and the junction with the IVC. This cryoablation interrupts the reentry around the IVC. After all of the cryoablations are finished, the other heart operation (eg, MV repair) is undergone.



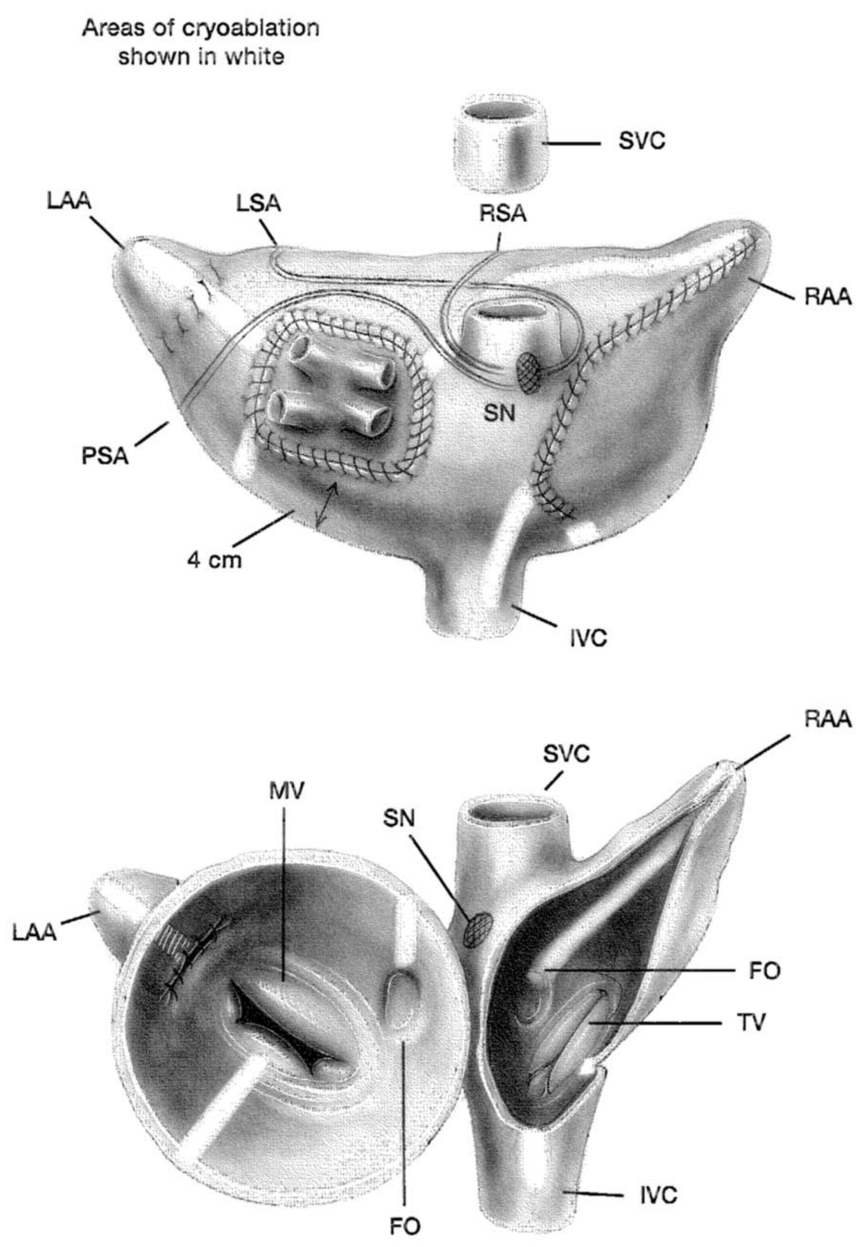
15 **Closing the left atrial appendage. The left atrial appendage is closed from the inside with a single continuous over-and-over suture. However, it is not a complete occlusion of the orifice. The orifice of the appendage is covered by the appendage wall because the orifice shape is round. Part of the left atrial appendage receives the left atrial pressure and secretes atrial natriuretic peptide. When the arrest time is prolonged, the left atrial appendage is tied simply from outside (see Kosakai-Maze [no. 2]).**



16 Closing the left atrium. The left atrium is closed from the inside with a single continuous over-and-over suture using 3-0 polypropylene (120 cm), as a mark is fitted to another mark. At first, we suture the left atrium between the left lower pulmonary vein (PV) and the left upper PV using the parachute technique. This suturing is extremely difficult, and it is necessary for an assistant to manually pull the left ventricle left and upward. Next we suture the left atrium between the left lower PV and the right lower PV. Then we put the mattress suture near the right upper PV for venting tube in order to fit the stump of the SVC to the original SVC. If both stumps are disengaged, the SVC cannot be connected. The left atrium between the left upper PV and the right upper PV and between the right lower PV and the right upper PV is sutured from the outside.

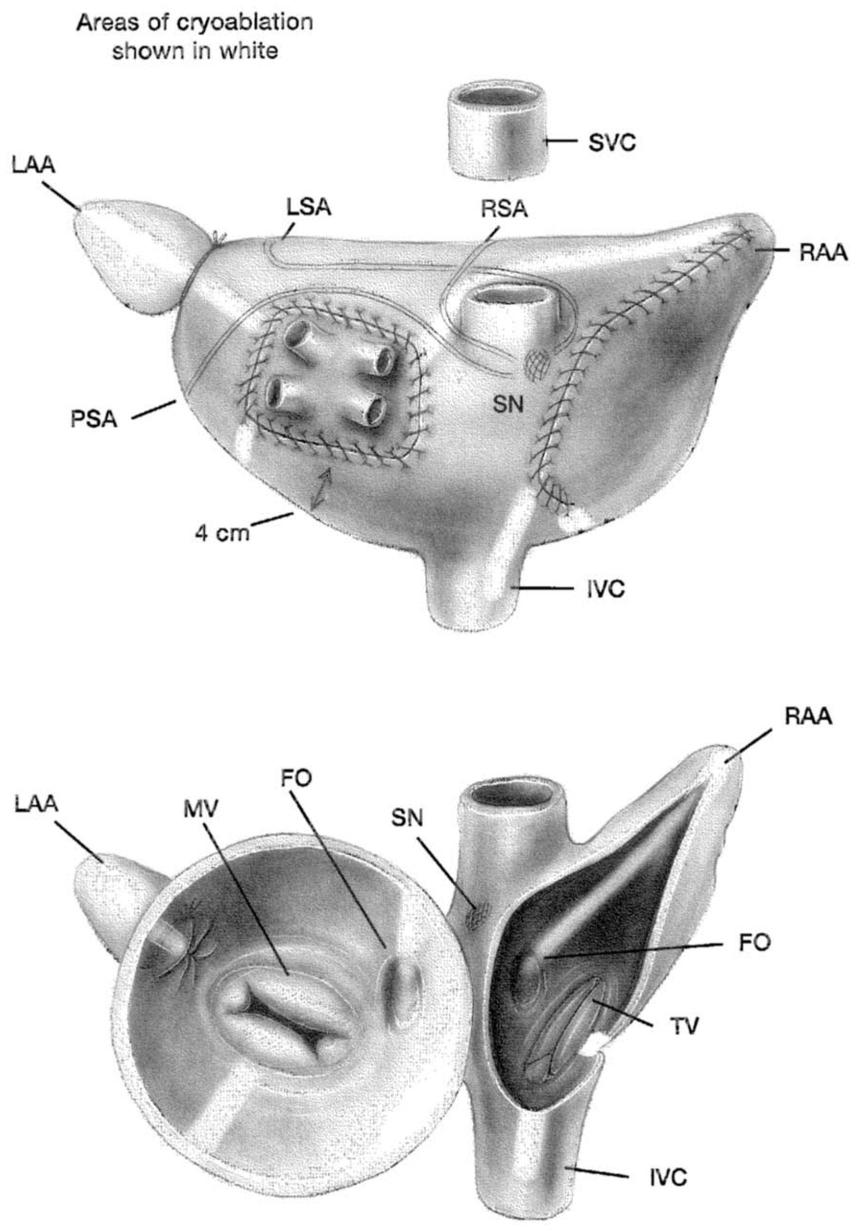


17 **Final schema of the Maze procedure. After the air in the left heart is evacuated completely, the aorta is unclamped. During beating heart, the right atrium and the SVC are sutured. The air in the right heart is evacuated from the pulmonary artery. At this point, the direct current cardioversion is performed. After the left ventricular venting tube from the right upper PV is pulled out, cardiopulmonary bypass is stopped. This schema shows the final aspect of suture line.**

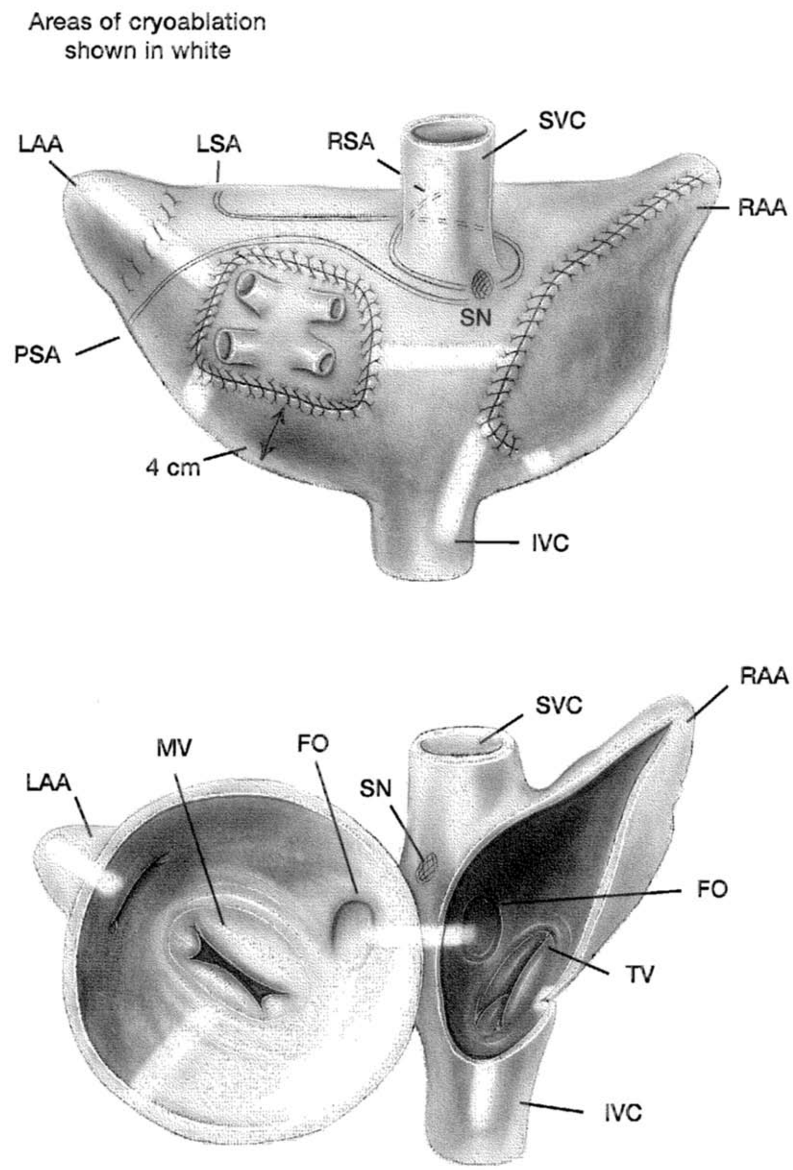


18 Kosakai-Maze (no. 1). This schema shows the standard Kosakai-Maze procedure.

Abbreviations: LAA, left atrial appendage; RAA, right atrial appendage; LSA, left sinus node artery; RSA, right sinus node artery; PSA, posterior sinus node artery; SN, sinus node; FO, fossa ovalis; TV, tricuspid valve.



19 Kosakai-Maze (no. 2). This schema shows one of the modifications of the Kosakai-Maze procedure. When the arrest time is prolonged, the left atrial appendage is tied simply from the outside.



20 Kosakai-Maze (no. 3). This schema also shows one of the modifications of the Kosakai-Maze procedure. If the SVC is not transected, the cryoablation of the left side of the atrial septum is difficult. Therefore, we perform the cryoablation behind the fossa ovalis instead of the incision, as in Maze III.

Postoperative Care

The Maze procedure is not a radical operation for AF. Therefore, a transient or sustained AF occurs soon after operation in approximately 50% of the patients who return to sinus rhythm. At 1 or 3 months postoperatively, we perform the direct current defibrillation just once.

In general, we do not administer any antiarrhythmic drug, unless AF or premature atrial contraction is observed. Administration of antiarrhythmic drugs that prolong the conduction time is contraindicated because these drugs might induce AF (despite the efforts to reduce the size of the atrium through the Maze procedure, extending the conduction time increases the size of the atrium).

Because the Maze procedure involves a complex incision and suture, there is still a possibility that thrombus will occur, and therefore anticoagulation therapy through warfarin is required for at least 3 months after operation. In patients who have not received an artificial valve, warfarin administration is stopped if the atrial contraction wave is confirmed by ultrasound Doppler examination 3 months postoperatively.

Comments

According to conventional differential diagnosis, the occurrence of atrial flutter and atrial tachycardia are determined only by the heart rate. The rate of atrial flutter is 250 to 350 per minute, and the rate of atrial tachycardia is 140 to 220 per minute. However, we found postoperative regular tachyarrhythmias with a rate of 220 to 300 per minute with isoelectric lines. We believe that these arrhythmias are attributable to micro reentries or the acceleration of automaticities. Forty percent of the postoperative residual supraventricular arrhythmia associated with MV disease is atrial tachycardia, which has isoelectric lines because of micro reentry or the acceleration of automaticities. The Maze procedure can inhibit macro reentry entirely. Atrial arrhythmia, which is difficult to cure, occurs because of micro reentry or acceleration of automaticity. Therefore, such atrial arrhythmia cannot be cured even by means of the Maze procedure. Consequently, we cannot deny that postoperative residual AF is not composed of multiple atrial tachycardias. We now believe that the success rate of the Maze procedure is influenced by the existence of micro reentry or acceleration of automaticity, and not by the technique for the Maze procedure. In the future, it will be very important to diagnose these causes preoperatively.

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